Summary of HVOF Testing and Experience

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Report Documentation Page

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Market Drivers

- Higher Life Expectancy from "today's" Aircraft Hydraulic Systems
- Higher Pressure Hydraulic System Designs
- Multiple Fluids for Hydraulic Systems
- Replacement of Hexavalent Chrome Coatings

Value

Performance

Technology

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HVOF vs. Chrome Testing

Pressure:	3,000 PSI Constant
Stroke:	3 Inch
Stroke Rate:	1 Hz
Fluid:	MIL-PRF-83282
Duration:	300,000 Cycles
Gland Dimensions:	Per MIL-G-5514 F, -214 2 BU Width
Gland Temperature:	250° F
Seals Tested	MoS_2 Filled PTFE vs. Elastomer AMS-P-83461 Contact
Rod Material	C1045 Steel
Coatings:	Tungsten Carbide/Cobalt (Wc-Co) Praxair D-Gun Process Ground & Superfinished to 2-4 µinch Ra
	Induction Hardened Chrome Plating – Hand polished to 6-10 µinch Ra

CHROME PLATE

TUNGSTEN CARBIDE

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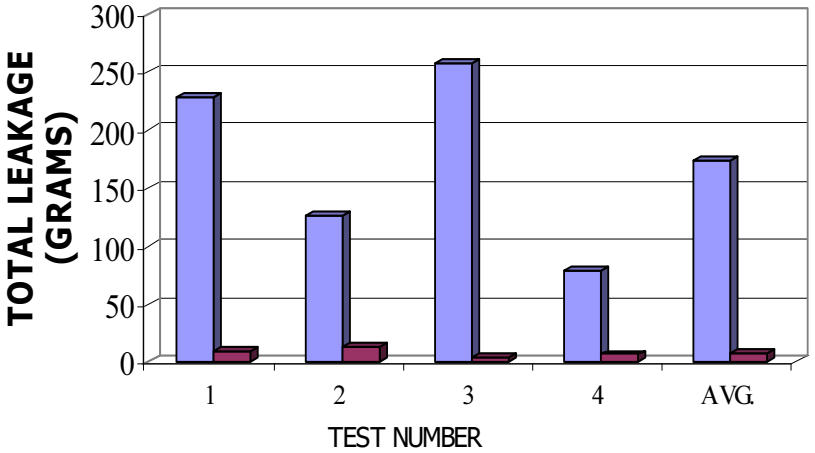
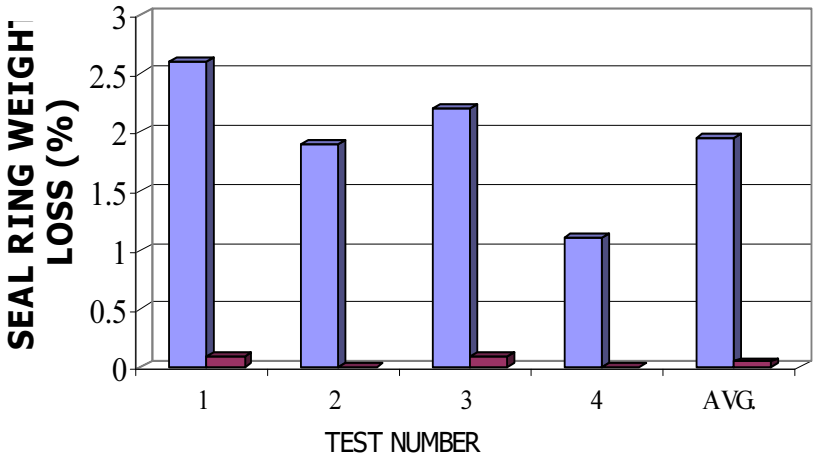
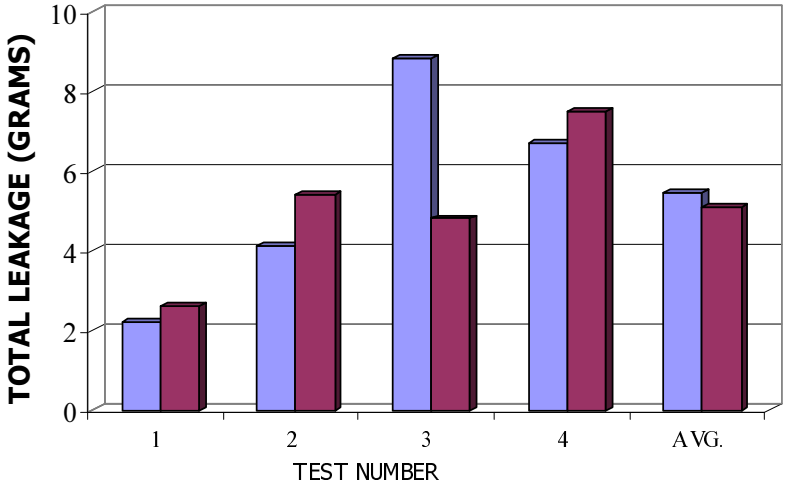
HVOF vs. Chrome Baseline Testing

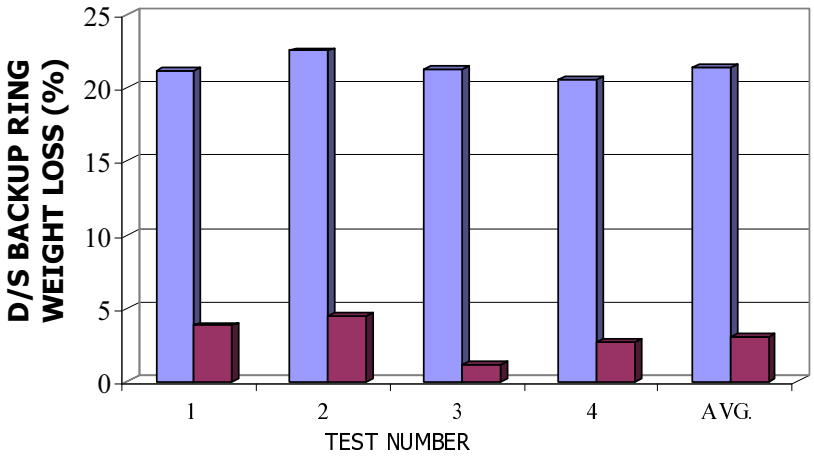
PTFE Contact Test Results





Elastomer Contact Test Results





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HVOF vs. Chrome Baseline Testing Conclusions

1) Based on PTFE and Elastomer Contact Seal performance in terms of leakage and wear, HVOF applied Tungsten Carbide coated Rods provide superior seal performance over Chrome plated Rods at stated finish levels (PTFE on HVOF averaged 8.5 gms leakage and 0.1% weight loss, while PTFE on Chrome averaged 173 gms leakage and 2% weight loss).

2) Test Results imply that HVOF applied Tungsten Carbide is at least equivalent to Chrome Plating (Elastomer Seal Leakage was consistent between two finishes while weight loss was roughly 10X PTFE).

3) Test Results confirm that Rod/Bore profile (not necessarily Ra alone) drastically affects seal performance. For Optimum Performance, control of peak height (Rp, Rpk) and bearing ratio (Tp, Mr) must also be achieved.

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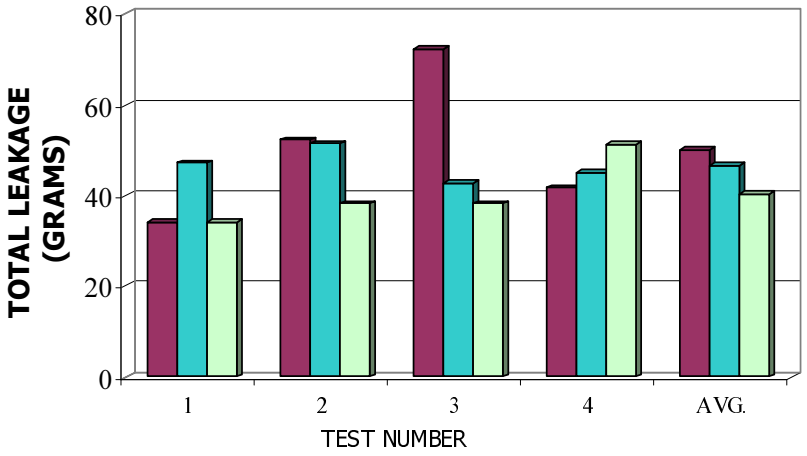
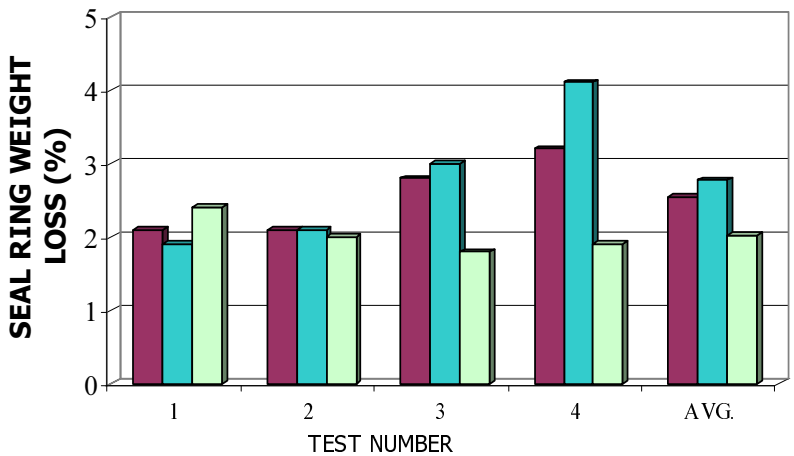
PTFE Contact Seals on Various HVOF Coatings

Pressure:	3,000 PSI Constant
Stroke:	3 Inch
Stroke Rate:	1 Hz
Fluid:	MIL-PRF-83282
Duration:	500,000 Cycles
Gland Dimensions:	Per MIL-G-5514F, -214 2 BU Width
Gland Temperature:	250° F
Seals Tested:	MoS_2 Filled PTFE Contact
Rod Material	C1045 Steel
Coatings:	1) Tungsten Carbide - Cobalt (83/17) @ 2-4 µinch Ra 2) Tungsten Carbide - Cobalt - Chrome (86/10/4) @ 2-4 µinch Ra 3) Tungsten Carbide – Chrome - Nickel @ 2-4 µinch Ra

PTFE Contact Seal Test Results of Various HVOF





TUNGSTEN CARBIDE

TUNGSTEN CARBIDE COLBALT CHROME

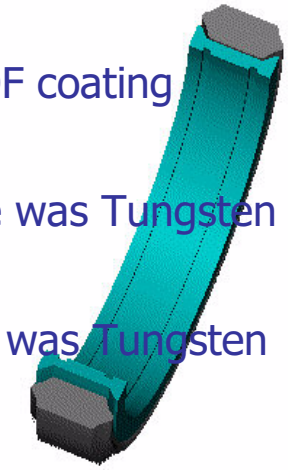
TUNGSTEN CARBIDE CHROME NICKEL

PTFE Contact Test Results and Conclusions

1) All three coating systems yielded consistent results regardless of HVOF coating composition applied.

2) All systems yielded between 40-50 grams leakage. Best performance was Tungsten Carbide Chrome Nickel at 40 grams.

3) All systems yielded between 2-2.75% weight loss. Best performance was Tungsten Carbide Chrome Nickel at 2%.



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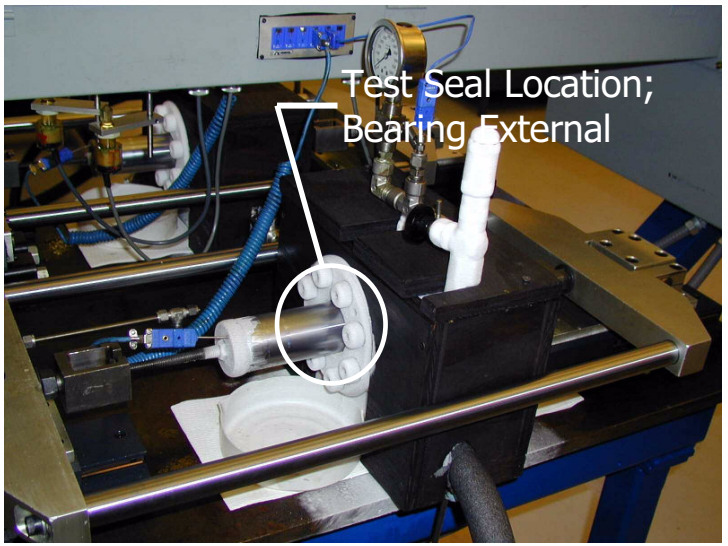
Landing Gear Testing Parameters

- Offset of .015" to one side, remaining side = .005"; approximate to .060" scaled to represent B767 Main Gear
- Pressure and Temperature testing profile models in-service conditions for LG as supplied by Boeing CAG
- Testing produced 2 active candidates for in-service evaluation at the Airline level
- Testing produced several designs that are continuously being developed and evaluated
- All test represent a minimum of 4 data points

Test Conditions

Pressure:	275 to 2500 psi
Gland Temp.:	-40ºF to ≤ 180ºF
Rod Material:	Steel with HVOF applied BMS 10-67
Rod Finish:	< 5 Ra Maximum
Fluid:	BMS 3-32 (Mil-H-5606 w/Lubrizol)

Test Condition	Oil Temperature	Pressure Extend (psi)	Pressure Retract (psi)	Total Cycles Upon Successful Test Completion
Takeoff Taxi	</= 150°F	2175	2500	105000
Cruise	-40°F Cooling	275	275	0
Landing Taxi	</= 150°F	1175	1500	105000
Landing	-40°F Start	275	2500	22500



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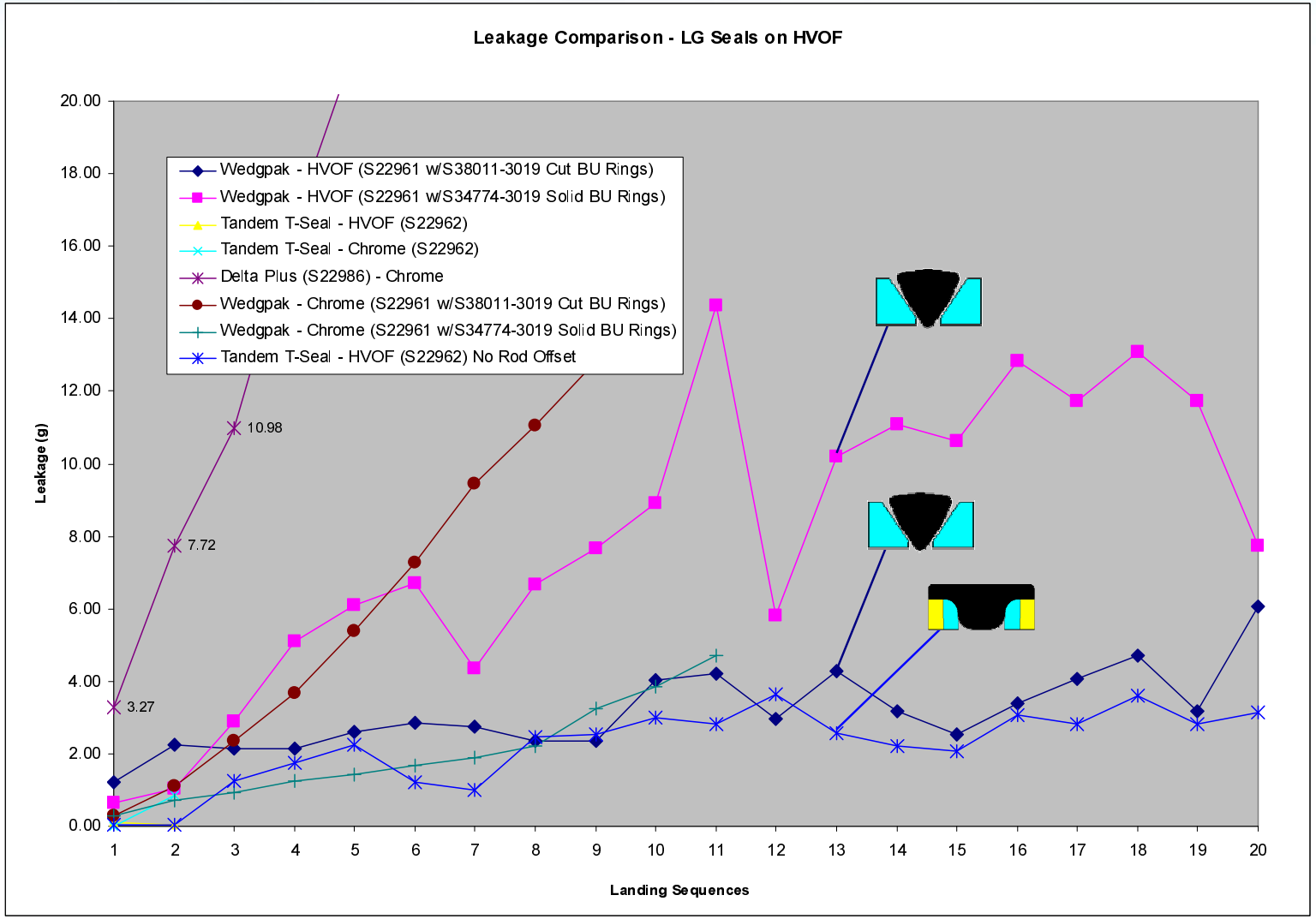
Test Summary Graph



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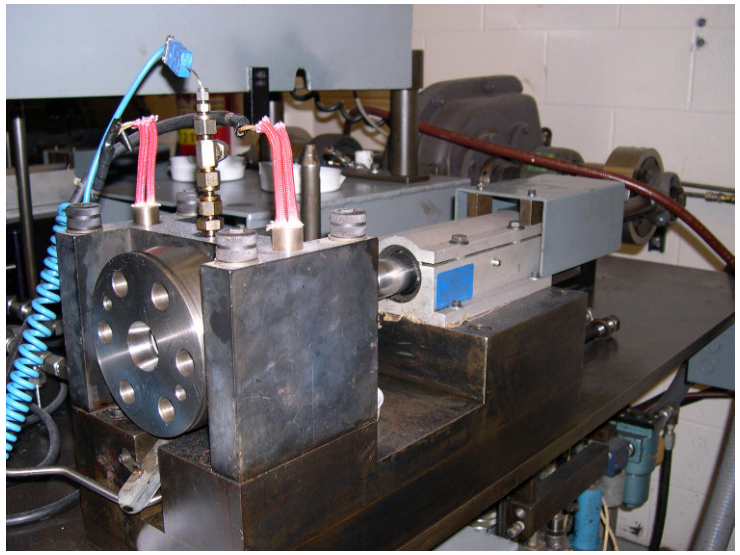
High Pressure Material Technology

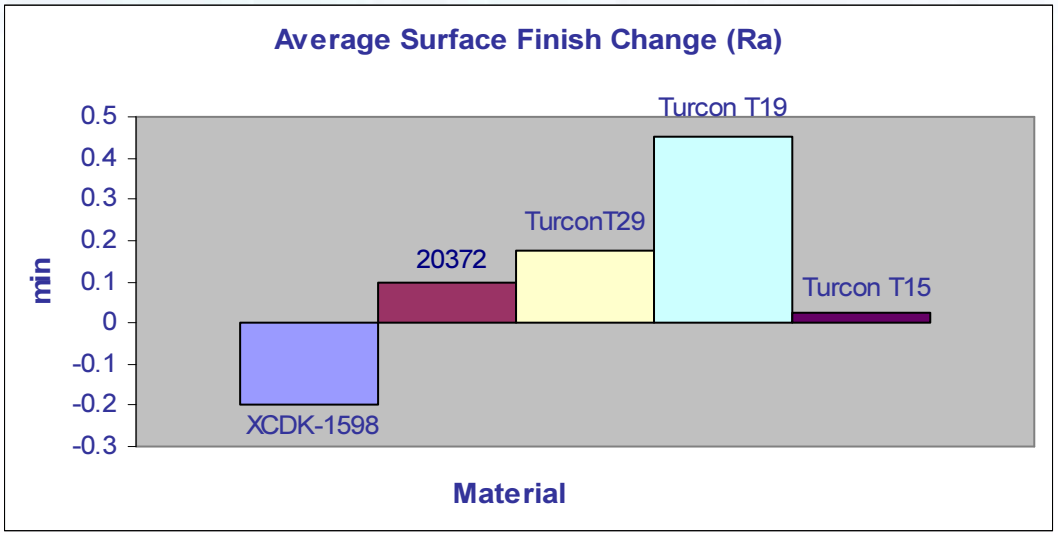
- Performance requirements developed from combined characteristics of several materials; best wear resistance (weight and wall loss), low friction performance, leakage control, non-abrasiveness to sliding hardware (impact on Roughness Average (Ra))

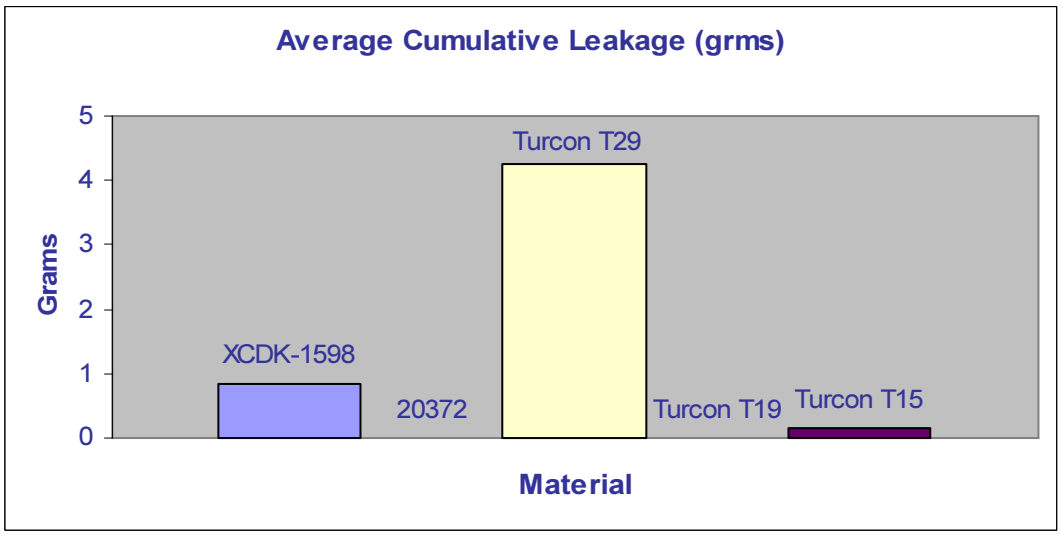
Test Parameters

Gland Temperature:	190ºF
Stroke:	.050”
Stroke Rate:	10 Hz
Pressure:	5000 psi constant
Rod Coating:	HVOF applied
	Wc-Co-Cr
Duration:	5,000,000 Cycles



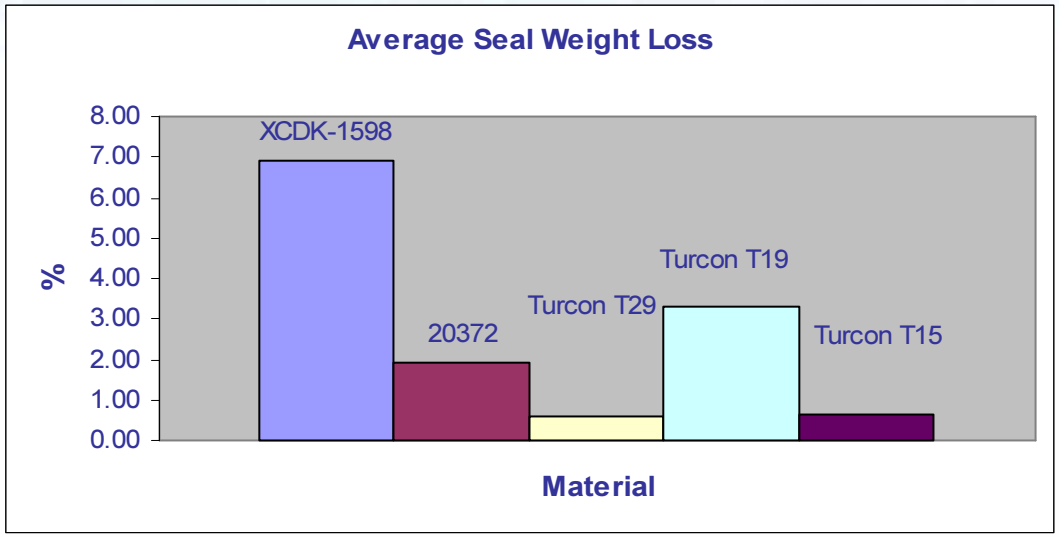
High Pressure Material Technology

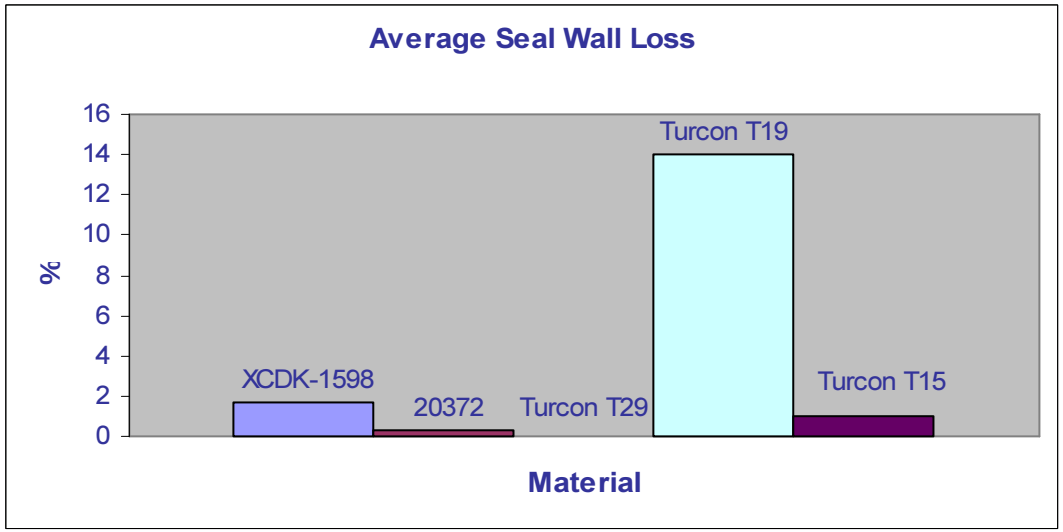




- Minimal impact on Ra
- Measurement Tolerance of "skidded" Profilometer
- Leakage performance equal to base-lined materials

High Pressure Material Technology





- Weight loss due to wear is minimal
- Wall loss due to wear is minimal

Value

Performance

Technology

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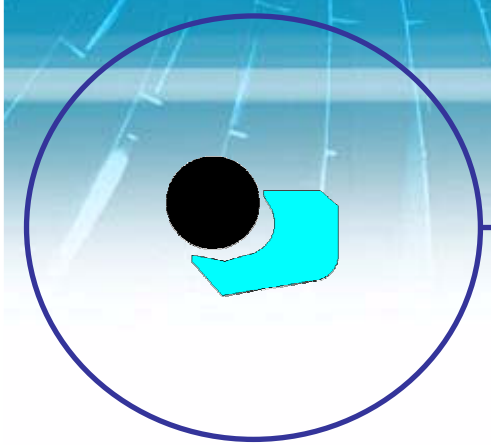
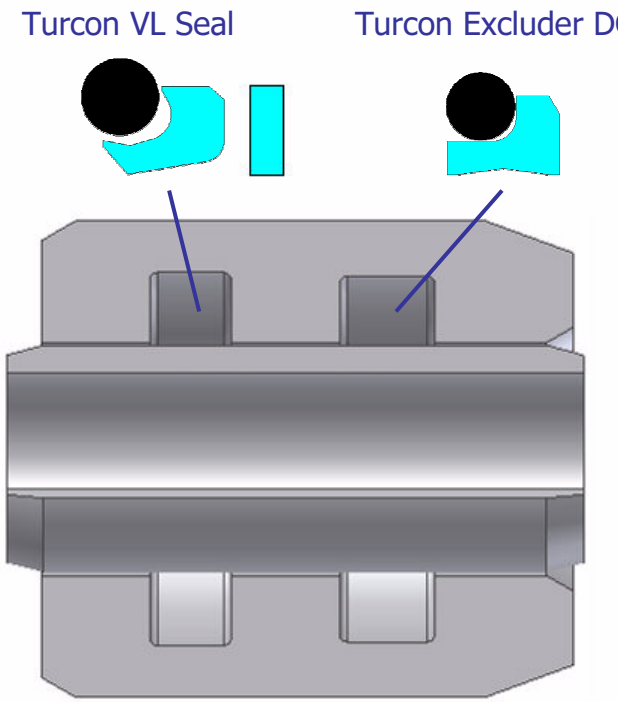
High Pressure Material Technology

High Pressure Non-abrasive PTFE Compound (20372)

- Thermoplastic-filled PTFE with proprietary lubrication package
- Improved wear resistance, leakage control and non-abrasiveness in high pressure systems
- Excellent lab test results supported by customer test results
- Strengthens Shamban Aerospace current material portfolio



High Pressure Material - Aerospace Case Study



APPLICATIONS
5k psi Development Program

MOTION
Reciprocating – with Dither

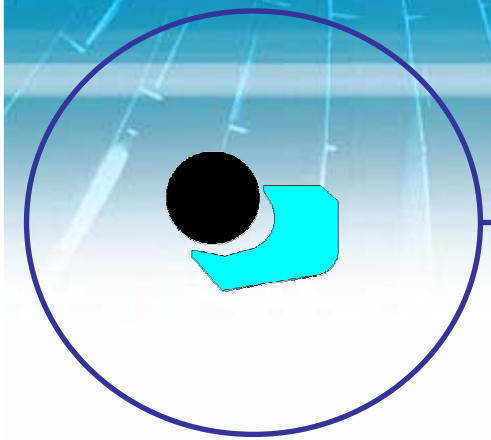
HARDWARE
Rod (HVOF) – < 5uin. Ra max.
Housing (Bare Steel) – 8uin. Ra max.

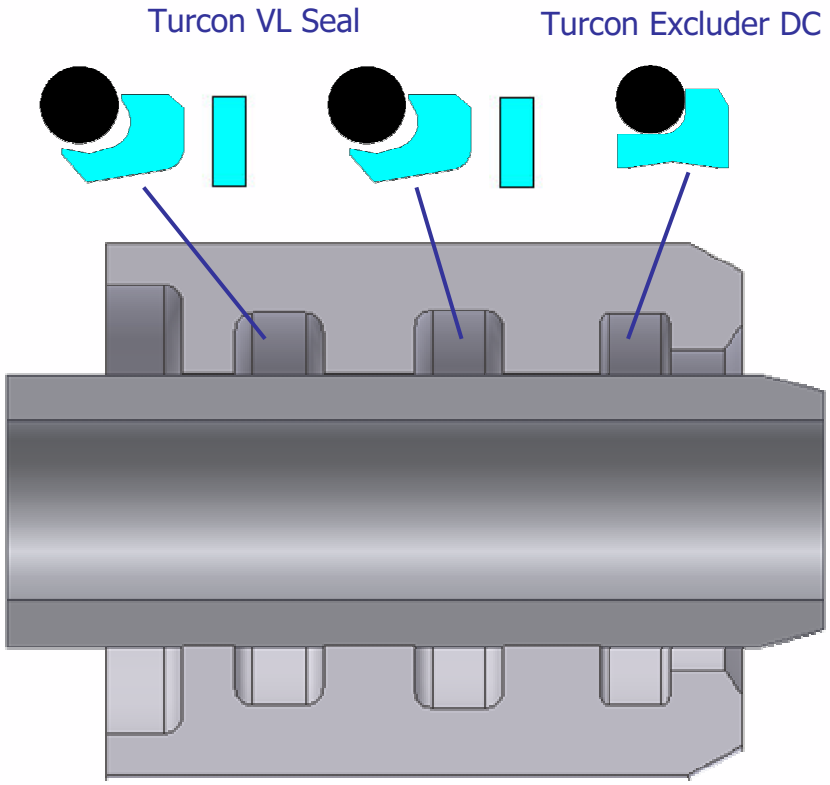
LEAKAGE MEASURED
- Zero (insufficient to form a drop)

SPECIFICATIONS

Media	Phosphate Ester
Speed	3 to 4 Hz
Stroke Length (in.)	4” Max.
Pressure	0 to 5000 psi
Temperature Range	-65F to 275F

Commercial Aircraft - Aerospace Case Study





APPLICATIONS

Outboard, Inboard Aileron and Elevator Actuators

MOTION

Reciprocating – with high Hz dither

HARDWARE

Rod (HVOF) – 4uin. Ra max.
Housing (Bare Steel) – 8uin. Ra max.

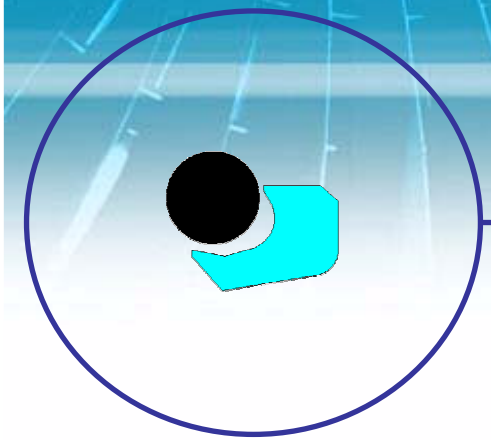
LEAKAGE MEASURED

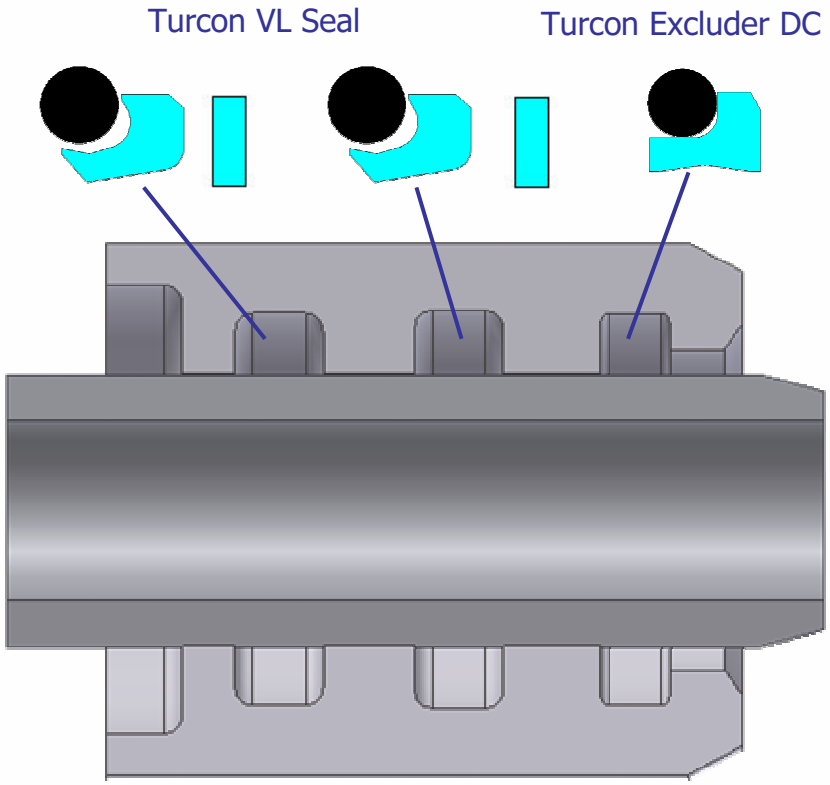
- Zero (insufficient to form a drop) In-service since early 2000. Performed to 30,000 Flight Hours.

SPECIFICATIONS

Media	Phosphate Ester
Speed	n/a
Stroke Length (in.)	2.95
Pressure	0 to 3000 psi
Temperature Range	-65F to 275F

Commercial Aircraft - Aerospace Case Study





APPLICATIONS
Yaw Damper

MOTION
Reciprocating – with 40 Hz dither

HARDWARE
Rod (HVOF) – 4uin. Ra max.
Housing - Unknown

LEAKAGE MEASURED
- Zero. Performed to 25,000 Flight Hours with less than 1 Drop/3,000 Cycles.

SPECIFICATIONS

Media	Phosphate Ester
Speed	n/a
Stroke Length (in.)	2.95
Pressure	0 to 3000 psi
Temperature Range	-65F to 275F

Value

Performance

Technology

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Conclusions on HVOF and Sealing Surfaces

Sealing Surface Finish

- Ra alone is insufficient to accurately describe a sealing surface
- Must control/measure other surface parameters such as Rp, Rpk, Rsk, Rtm and tp
- Sealing surface recommendations:
  - Ra - < 5 µin
  - Rp - 8 µin maximum
  - Rtm - 40 µin maximum
  - Rsk - negative
  - tp - 70 -90 % @ depth of p = 0.25 Rtm relative to reference line = 5 % tp

Sealing Surface Coatings

- Standard coatings are quickly becoming HVOF applied technology.
- Alternative chrome coatings; HVOF have demonstrated excellent performance.
- The combination of advanced coatings and surface finish technology has proven effective at improving seal system performance; leakage control, seal wear and service life for "today's" generation of Aircraft hydraulic systems.